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**METHOD AND APPARATUS FOR INCREASING
CAPACITY OF MAGNETIC MEDIA STORAGE**

RELATED APPLICATIONS

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The present application is related to commonly assigned, co-pending U.S. Patent Applications Serial Nos. 10/394,876 entitled "DOUBLE SIDED MAGNETIC TAPE", filed on March 21, 2003, and 10/115,040 entitled "METHOD FOR
10 PACKING TAPE ON A SPOOL WITHOUT TAPE EDGE WEAR", filed on April 2, 2002, which are hereby incorporated by reference.

BACKGROUND OF THE INVENTION

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1. Field of the Invention:

The present invention relates generally to high track density, flexible media storage applications, and more specifically, but not exclusively, to a method and
20 apparatus for increasing the capacity of magnetic media storage. More specifically, the present invention provides an improved two-sided magnetic tape.

2. Background of the Invention:

25 Magnetic tape continues to be a popular medium for recording and storing information. For example, magnetic tape storage systems may hold vast quantities of data at a relatively low cost per bit stored. Magnetic tapes are easily manipulated by automated storage systems. Data
30 may be added to information already stored on a magnetic tape. In addition, magnetic tapes may be erased and

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rerecorded. Furthermore, magnetic tape has a relatively long shelf life under proper storage conditions.

Magnetic tape and tape storage systems may be made increasingly more efficient and cost-effective by
5 increasing the data storage density. Traditionally, increases in storage density have resulted from narrower data tracks, increases in the number of data tracks per tape width, increases in the density of data recorded along the length of each track, etc. These increases
10 have resulted from improvements in the magnetic media, tape thickness, read and record electronics, tape head positioning, data encoding and decoding schemes, etc. However, all of these improvements have focused on the traditional tape configuration of a supportive web coated
15 with magnetic material on one side.

A doubling of information density can be achieved if both sides of the supporting web are coated with magnetic material for recording and retrieving information. However, such two-sided magnetic tape schemes have been
20 considered to be impractical for a number of reasons. For example, one problem with two-sided magnetic tape is related to a phenomenon called "print-through," in which the data written on the media located on one side of the magnetic tape affects the magnetization of the media
25 located on the other side. A related problem is called "contact recording" that can occur when the magnetic tape is spooled up on a reel. In this case, the two sides of the tape are in close proximity or physically touching when the tape is stored, which can cause errant
30 magnetization of the media on either side. The use of a

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thicker media can help to reduce print-through and/or contact recording, but a thicker media also reduces the volumetric storage capacity of the magnetic tape.

Another problem with two-sided magnetic tape arises during tape spooling operations. Tape pack winding issues can arise with two-sided magnetic tape, because the surface(s) of one or both sides of the tape may be too smooth or too rough. For example, when relatively smooth two-sided magnetic tape is spooled at speed (e.g., with air entrainment), tape slippage (resulting from the relative smoothness of both sides) can cause such problems as stagger wraps, tape edge damage, etc. The use of a rougher surface on one side of the tape can mitigate such problems. Having too rough a surface on one side of a tape typically precludes the use of high-density recording on the magnetic media of the other side due to mechanical imprint/embossing.

Therefore, it would be advantageous to provide an improved two-sided magnetic tape that can increase storage capacity and also mitigate tape pack winding and similar problems.

SUMMARY OF THE INVENTION

The present invention provides a method and apparatus for increasing the capacity of magnetic media storage. More specifically, the present invention provides an improved two-sided magnetic tape. In accordance with a preferred embodiment of the present invention, to mitigate pack winding problems, a trade-off can be made between the back-coat roughness of a side of the magnetic tape and the mechanical imprint of that roughness in the recording surface of that side (e.g., compromise between roughness and recording density). For example, a recording density and coding scheme deemed appropriate for a larger recording head-to-media separation or spacing can be used for the "rougher" side of a two-sided tape, and the highest recording density achievable can be used for the "best" or smoothest side of the two-sided tape. Depending on the recording density/roughness match selected, an optimum capacity gain can be selected from a range of capacity gains having values between 1 and 2 (e.g., $1 < (\text{gain in capacity}) < 2$). Thus, for relatively slow spooling applications, an optimum recording density/roughness match can be selected with less roughness for the tape surface(s) involved, and for relatively fast spooling applications, an optimum recording density/roughness match can be selected with more roughness for the tape surface(s) involved.

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features believed characteristic of the
5 invention are set forth in the appended claims. The
invention itself, however, as well as a preferred mode of
use, further objectives and advantages thereof, will best
be understood by reference to the following detailed
description of an illustrative embodiment when read in
10 conjunction with the accompanying drawings, wherein:

Figure 1 depicts a diagram illustrating a tape drive
system in which the present invention may be implemented;

Figure 2 depicts a pictorial representation of a
side view of a two-sided tape that may be used to
15 implement a preferred embodiment of the present
invention;

Figure 3 depicts a partially expanded side view of
the two-sided tape depicted in **Figure 2**; and

Figure 4 depicts a flowchart illustrating a method
20 for increasing the capacity of a magnetic tape, in
accordance with a preferred embodiment of the present
invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

With reference now to the figures, **Figure 1** depicts a diagram illustrating an exemplary tape drive system in which the present invention may be implemented. For this illustrative example, tape drive system **100** includes tape reels **102**, **104**. Reels (or spools) **102**, **104** can be used for spooling or unspooling two-sided tape media **105** including first side **106** and second side **108**. First read/write head **110** is positioned adjacent and in close proximity to first side **106** for reading and writing data from and to a magnetic storage media formed on first side **106**. Second read/write head **112** is positioned adjacent and in close proximity to second side **108** for reading and writing data from and to a magnetic storage media formed on second side **108**. Rotation of reels **102**, **104** clockwise or counter-clockwise moves first side **106** of tape media **105** in a horizontal direction (denoted by arrows **114**) past first read/write head **110**, and second side **108** in the same horizontal direction past second read/write head **112**. For clarity, only pertinent sections and/or components of tape drive system **100** are shown. In this regard, tape drive system **100** shown in **Figure 1** is intended only as an illustrative example, and not as an architectural limitation for the present invention.

Figure 2 depicts a pictorial representation of a side view of an exemplary two-sided magnetic tape that may be used to implement a preferred embodiment of the present invention. For example, magnetic tape **200** shown in **Figure 2** may represent tape media **105** shown in **Figure**

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1. For this illustrative example, magnetic tape 200 includes flexible substrate 202 onto which has been deposited two recording surfaces 204, 206. The two recording surfaces include first magnetic coating 203 on
5 first tape side 204, and second magnetic coating 205 on second tape side 206. During a recording process, regions of magnetization are formed in first magnetic coating 203 and second magnetic coating 205 by a write portion of an adjacent read/write head (e.g., read/write
10 heads 110, 112, respectively, in **Figure 1**). Similar to the direction of tape movement in **Figure 1**, magnetic tape 200 moves in a horizontal direction (as denoted by arrow 208) relative to the adjacent read/write heads.

Notably, in accordance with the present invention,
15 magnetic tape 200 is formed with recording surfaces 204, 206 having different degrees of roughness. As such, for this exemplary embodiment, first magnetic coating 203 is formed with a smoother surface than second magnetic coating 205. Also, first magnetic coating 203 can be
20 formed as a high-density recording surface, and second magnetic coating 205 can be formed as a medium-density recording surface. In other words, for this exemplary embodiment, first tape side 204 of magnetic tape 200 can have a state-of-the-art (e.g., relatively smooth, thin)
25 surface optimized for high-density recording, and second tape side 206 can have the roughness of its surface degraded for medium-density recording and also to aid or enhance operations of spooling the tape into reels (or spools).

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Figure 3 depicts a partially expanded side view of the two-sided tape depicted in **Figure 2**. For example, magnetic tape 300 shown in **Figure 3** may represent magnetic tape 200 shown in **Figure 2**, with selected portions of magnetic tape 200 expanded for illustrative purposes. For this illustrative example, magnetic tape 300 includes flexible substrate 302 on which has been deposited recording surfaces 304, 306. The two recording surfaces include first magnetic coating 310 on first tape side 304, and second magnetic coating 308 on second tape side 306. First read/write head 312 is positioned adjacent and in close proximity to the recording surface of first tape side 304 (e.g., outer surface of first magnetic coating 310), and second read/write head 314 is positioned adjacent and in close proximity to the recording surface of second tape side 306 (e.g., outer surface of second magnetic coating 308). Coating 308 and 310 can be of single or multi-layer construction.

The distance, d_1 , or effective (e.g., average or median) spacing between first read/write head 312 and the surface of first magnetic coating 310 is denoted, for this example, as first head-to-media spacing 316. The distance, d_2 , or effective (e.g., average or median) spacing between second read/write head 314 and the surface of second magnetic coating 308 is denoted, for this example, as second head-to-media spacing 318. Similar to the direction of tape movement in **Figures 1** and **2**, magnetic tape 300 moves in a horizontal direction (as denoted by arrow 320) relative to adjacent read/write heads 312, 314. Notably, for this illustrative example,

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second head-to-media spacing 318 is greater than first head-to-media spacing 316, because the surface of second magnetic coating 308 has been selected to be rougher than the surface of first magnetic coating 310.

5 **Figure 4** depicts a flowchart illustrating a method for increasing the capacity of a magnetic tape, in accordance with a preferred embodiment of the present invention. Essentially, a recording density and coding scheme deemed appropriate for a relatively large head-to-
10 media spacing can be used for the "rougher" side of the two-sided tape, and the highest recording density achievable (and as desired) can be used for the "best" or smoothest side of the two-sided tape. Depending on the recording density/roughness match selected, an optimum
15 capacity gain can be selected from a range of capacity gains with values between 1 and 2 (e.g., $1 < (\text{gain in capacity}) < 2$). Thus, for relatively slow spooling applications, an optimum recording density/roughness match can be selected with less roughness for the tape
20 surface(s) involved, and for relatively fast spooling applications, an optimum recording density/roughness match can be selected with more roughness for the tape surface(s) involved.

Specifically, referring to **Figures 3** and **4** for this
25 exemplary embodiment, method 400 begins by a user (e.g., a designer) formulating a magnetic coating to be formed on a supportive web (e.g., flexible substrate 302 in **Figure 3**) in order to produce the "best" or smoothest surface on one side of a two-sided magnetic tape (step
30 402). For illustrative purposes, the "best" side of the

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two-sided magnetic tape having the "smoothest" surface is referred to hereinafter as "Side 1", and the second side of the two-sided magnetic tape having a "rougher" surface is referred to hereinafter as "Side 2".

5 Generally, a two-sided magnetic tape may be fabricated by any one of a number of techniques. For example, the flexible substrate can be composed of any appropriate flexible material or coating, such as Polyethylene Teraphalate (PET), Polyethylene Napthalate
10 (PEN), ARAMID, PbO, etc. The substrate can be pulled past a coating head, which injects or deposits an under-layer onto one side of the substrate and a magnetic coating onto the under-layer. The magnetic coating can be composed of magnetic particles mixed with a polymeric
15 binder. The magnetic particles may be filtered to include particles of similar size. The substrate can be pulled past a second coating head, which injects or deposits an under-layer onto the second side of the substrate and a magnetic coating onto that under-layer.
20 A coating process including suitable coating heads for manufacturing two-sided magnetic tape is described in U.S. Patent No. 5,069,934 to Chino et al., which is incorporated by reference herein.

 A coating process for manufacturing two-sided
25 magnetic tape may also include the expelling of magnetic material through a vapor deposition process such as sputtering, evaporation, etc. Also, a coating process for manufacturing two-sided magnetic tape may include, for example, a thin film deposition process for coating
30 one side of the tape, and a particulate application

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process for coating the second side. In any event, the particular magnetic coating process used for manufacturing a two-sided magnetic tape can vary by application, and should not be considered as an architectural limitation on the present invention.

Table 1 (below) shows parameters with exemplary values that can be used to design and/or fabricate a magnetic coating for each surface of a two-sided magnetic tape (e.g., Side 1 or the surface of first magnetic coating 310, and Side 2 or the surface of second magnetic coating 308 in Figure 3).

TABLE 1. Parameters to Produce Lower Density Recording on Side 2 Compared to Side 1 Using SNR Criteria of >24dB

Parameter	Side 1	Side 2 (A)	Side 2 (B)	Side 2 (C)	Side 2 (D)
Media Particle Density, n, particles cm ⁻³	3.00E+16	2.00E+16	1.00E+16	5.00E+15	2.00E+15
Media Magnetic Coating Thickness, microns	0.15	0.25	0.3	0.4	0.6
Effective spacing due to roughness, d micron	0.06	0.1	0.15	0.2	0.3
Read Track Width, W microns	4.0	4.0	4.0	4.0	8.0
Recording Density, kfc/i	200	145	100	70	55
Trk Pitch, microns	10	10	10	10	15
Track Density, trks/cm	1000.0	1000.0	1000.0	1000.0	666.7
Track Density, tpi	2540.0	2540.0	2540.0	2540.0	1693.3
Recording Density, frmm	7874.0	5708.7	3937.0	2755.9	2165.4
Recording Wavelength, microns	0.254	0.350	0.508	0.726	0.924
Wavenumber, k microns ⁻¹	24.7	17.9	12.4	8.7	6.8
Recording Density, kbpi (PRML)	396	287.1	198	138.6	108.9
SNR (ideal)	1290.3	1636.6	1720.4	1755.5	2274.9
Loss due to spacing, e ^{-kd}	0.227	0.166	0.156	0.177	0.130
Areal Density, Gb/in ²	1.01	0.73	0.50	0.35	0.18
SNR (dB)	24.7	24.4	24.3	24.9	24.7
Relative Capacity of each side	1	0.73	0.5	0.35	0.18
Relative Capacity for 2 sides	2	1.73	1.5	1.35	1.18

For this exemplary embodiment, the Signal-to-Noise Ratio (SNR) used may be defined as:

$$\text{SNR (dB)} = n W \lambda^2 e^{-kd} / 6, \quad (1)$$

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where the parameter "n" represents the Media Particle Density (particles cm^{-3}), "W" represents the Read Track Width (microns), " λ " represents the Recording Wavelength (microns), " e^{-kd} " represents losses due to the head-to-media separation for the tape surface involved, "k" represents the Wavenumber (microns^{-1}), and "d" represents the effective head-to-media spacing/separation (microns) due to the roughness of the tape side involved.

Referring to **Table 1**, Side 1 can be formed with a state-of-the-art thin, smooth magnetic coating (e.g., coating 310) to produce a relatively small, effective head-to-media separation, d_1 (e.g., compared to coating 308 of Side 2). Preferably, Side 1 is to be used for high recording density based on the SNR selected to meet the minimum requirements established by the user for reliable data recording. An exemplary minimum SNR criterion of greater than 24dB has been selected for illustrative purposes. However, the present invention is not intended to be so limited, and any appropriate SNR criterion (e.g., 15dB, 18dB, 20dB, etc.) for a particular two-sided magnetic tape design or application may be used.

For this example, referring to the column labeled "Side 1" in **Table 1**, in order to satisfy Equation (1) above, a coating thickness of 0.15 microns can produce an effective head-to-media spacing, d_1 , of 0.06 microns (e.g., thin, smooth surface) for a desired SNR of 24.7dB. Also, to achieve the desired SNR of 24.7dB, the media particle density, n, of the magnetic coating of Side 1 is $3.00\text{E}+16$ particles cm^{-3} , the Recording Wavelength, λ , is

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0.254 microns, and the loss due to spacing, e^{-kd} , is 0.227. As such, each parameter listed in the column labeled "Side 1" in **Table 1** has a representative value that can satisfy Equation (1).

5 Next, the user determines a surface roughness needed for Side 2 of the two-sided magnetic tape to produce a desired level of tape spooling performance (step 404). For example, in order to minimize tape pack winding and similar spooling problems, a relatively fast tape
10 spooling operation may require the use of a rougher magnetic coating surface, and a relatively slow tape spooling operation may require the use of a smoother magnetic coating surface. The user then calculates or measures the effective head-to-media spacing, d_2 , which
15 results from the surface roughness selected for Side 2 (step 406).

For example, referring to the column entitled "Side 2(A)" in **Table 1**, an effective head-to media spacing, d_2 , of 0.1 microns can be used to produce a desired level of
20 tape spooling performance for a first application. Another exemplary, effective head-to-media spacing, d_2 , of 0.15 microns can be used to produce a desired level of tape spooling performance for a second application (e.g., referring to the column entitled "Side 2(B)" in **Table 1**).
25 Still another exemplary, effective head-to-media spacing, d_2 , of 0.2 microns can be used to produce a desired level of tape spooling performance for a third application (e.g., referring to the column entitled "Side 2(C)" in **Table 1**). Similarly, yet another exemplary effective
30 head-to-media spacing, d_2 , of 0.3 microns can be used to

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produce a desired level of tape spooling performance for a fourth application (e.g., referring to the column entitled "Side 2(D)" in **Table 1**). At this point, it should be understood that although **Table 1** provides a list of exemplary parameter values for four different versions (e.g., 2A-2D) of Side 2 for a two-sided magnetic tape, these values are provided for illustrative purposes and should not be considered as architectural limitations on the present invention.

Considering the desired "roughness" of Side 2, the user calculates a recording density that can be attained with the calculated or measured effective head-to-media spacing, d_2 , and an SNR criterion desired for reliable data recording for Side 2 (step 408). For example, referring to the column Side 2(A) in **Table 1**, for a desired SNR criterion of 24.4dB, and an effective head-to-media spacing, d_2 , of 0.1 microns, a recording density of 287.1 kbp/s may be attained for Side 2. As another example, referring to column Side 2(D) in **Table 1**, for a desired SNR criterion of 24.7dB, and an effective head-to-media spacing, d_2 , of 0.3 microns, a recording density of 108.9 kbp/s may be attained for Side 2. The user can then design a recording head and associated data channel to produce the calculated recording density attainable for Side 2 in accordance with the parameter values in **Table 1** and/or derived from Equation (1) above (step 410).

The description of the present invention has been presented for purposes of illustration and description, and is not intended to be exhaustive or limited to the

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invention in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art. The embodiment was chosen and described in order to best explain the principles of the invention, 5 the practical application, and to enable others of ordinary skill in the art to understand the invention for various embodiments with various modifications as are suited to the particular use contemplated. Also, it should be understood that specific manufacturing 10 techniques and processes that can be used to fabricate and coat magnetic tapes are known to those of ordinary skill in the art, and that these specific techniques and processes need not be described herein in unnecessary detail in order to enable those of ordinary skill to make 15 and use the present invention.